THE UNIVERSITY OF ALBERTA

SCANNING OF LENGTH INFORMATION IN STM AND MSTM

by

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ABSTRACT

Retrieval of STM and MSTM length information was investigated through the use of a modified speeded recognition paradigm. Positive response criterion varied from physical matches, to category matches, to both physical and category matches. The stimulus set consisted of rods varying in length and diameter. Experiment I investigated the notion of a parallel scan of perceptual and conceptual codes for the same stimulus information. The notion was supported by statistical significance in the STM task and by basic calculations in the MSTM task. It was also found that length information can be coded uninfluenced by diameter. On the basis of the results obtained in the first experiment, a second STM experiment was warranted. Perceptual and conceptual memory codes for length information were independently manipulated. This lent further support to a dual code retrieval notion.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Survival in a fluctuating environment has as a prerequisite, flexibility. Physiologically limited, man relies on cognition to adapt and extend his environmental survival bandwidth. In the last decade, research has been initiated investigating cognitive flexibility within man's retrieval processes. Specifically, this research has been concerned with verifying the presence and parameters of multiple independent storage codes for the same stimulus input. Retrieval, as an offshoot, becomes a function of accessing and searching the optimal code or codes for the particular task demand. Performance then, emerges as the result of a flexible, optimal cognitive process.

In theoretical support of multiple stimulus storage codes is a notion proposed by Atkinson, Herrmann and Wescourt (1974). According to their theory, cognitive retrieval processes revolve around perceptual and conceptual codes. Perceptual codes represent visual or phonetic stimulus information, or that information existing at a purely physical* level. A stimulus has a number of perceptual codes corresponding to modality and context of presentation. These codes form an array around a conceptual code. Conceptual codes are akin to primitive meaning features not dependent on physical form. Each conceptual code with its appropriate perceptual array forms a conceptual store node. In short term memory (STM) tasks, perceptual or conceptual codes of the incoming stimuli are mapped into short term store (STS). Which of the two codes are contained in STS is a function of task demand. In those tasks demanding speed or response solely on a physical level, STS contains a disproportionate amount of perceptual codes. Those tasks

*Physical refers to an instance rather than information necessarily isomorphic to the external event.

requiring semantic comparisons, on the other hand, involve a disproportionate amount of conceptual codes. To summarize, the theory proposes a serial encoding process of perceptual to conceptual code. The two codes are anchored at a particular conceptual node, and thus both are stored in memory. Either code can be mapped into STS and consequently searched. Extending the theory toward a notion of cognitive flexibility requires only that one, or both, codes be transferred into STS. Retrieval then becomes a function of search of the optimal code or codes for the particular task demand.

Empirical support of a dual code retrieval theory is drawn from experiments utilizing reaction time (RT) as the dependent measure. RT, traditionally, is utilized in conjunction with STM speeded recognition paradigms. Speeded recognition paradigms employ the following format. The subject (S) is initially familiarized with a stimulus ensemble consisting of all items which may occur as a test item. Within this ensemble exists the experimenter defined memory set, which is that varying or fixed set of items presented to S to memorize before every trial. All remaining items form the negative set. Upon presentation of the test item or probe, S makes either a positive response if he recognizes the probe to be a member of the memory set, or a negative response if he believes the probe to be a member of the negative set (Sternberg, 1969). The resulting RT, or time between probe presentation and response, is indicative of the time required for the cognitive processing and muscle activation eventuating in response. RT then, becomes more than a simple latency. Simple latency infers a direct link between signal detection and response initiation (Fitts and Posner, 1967). RT, in this case, infers probe recognition, comparison of probe

to memory set items, decision, and response execution (Sternberg, 1969). The increased task complexity, along with the speeded response inherent in a speeded recognition paradigm, brings forth the question of error. The aim of speeded recognition paradigms is the study of error-free processing (Sternberg, 1969). Thus, though speed is essential in limiting the cognitive processing undertaken, error rates must not exceed approximately twelve percent if error-free processing is to be complied with.

RT has traditionally been decomposed into a series of unique stages accounting for hypothesized cognitive processes occurring between stimulus presentation and response. The most influential at the present time is a theory proposed by Sternberg (1969). In speeded recognition paradigms where errors are extremely low (ten to twelve percent), four discrete stages are hypothesized to occur between stimulus presentation and response: stimulus encoding, serial comparison, binary decision, and translation and response organization. Plotting response as a function of RT versus memory set size allows inferences to be drawn about the various stages. Encoding, decision time, translation and response organization are proposed to influence the intercept. Serial comparison, the suggested retrieval process, is seen to influence the slope of the line.

Sternberg's hypothesis of a serial comparison retrieval process has been the object of much contention. Though evidence has accumulated in its favor (Briggs and Blaha, 1969; Wingfield and Bolt, 1970), facts have also accumulated indicating a parallel scanning process (Atkinson, Holmgren, and Juola, 1969; Murdock, 1971; Okada and Burrows, 1974).

Intuitively, a strictly serial comparison process would nullify the benefits of dual retrieval codes. Even more detrimental is Sternberg's hypothesis of a serial exhaustive scan. In this case dual codes, if both were present in STS, would only act to double retrieval time. Dual retrieval codes and a serial comparison process only become compatible if the two codes can be scanned in a parallel fashion. Though scanning within each code may be a serial process, the necessity for simultaneous initiation of scanning of the various codes is a vital factor to an optimal retrieval process.

Independent retrieval codes necessarily infers a different slope for each code, as slope reflects retrieval in a speeded recognition paradigm. Perceptual and conceptual retrieval codes are teased out by varying response criterion or match type within the paradigm. Three criteria are generally incorporated; physical matches, category matches and both physical or category matches. Physical matches require a positive or negative response based on physical properties. If the probe is perceptually identical to one of the memory set items, a positive response should occur. Category matches require a positive or negative response based on the conceptual classification of a category label to a memory set of various category exemplars, or vice-versa. Positive responses to both matches should result from a probe being either physically or categorically identical to any item in the memory set, and thus involve either perceptual or conceptual classification. Analysis of the slopes of the three resulting response functions not only provides information concerning retrieval codes for the different match types, but also provides information regarding a parallel scan of

the codes. With the event of differing slopes for perceptual and conceptual codes, and the slope for both matches being less than the sum of the slopes for physical match and conceptual match (indicating a parallel scan of the two codes), a second experiment must be conducted.

The second experiment is to insure the codes are in fact independent, and are not just separate facets of a single trace. The codes can be independently manipulated through the use of the both match condition. Positive trials are delineated into fragmented and whole halves. Fragmented trials parallel the both match condition mentioned above. Whole trials vary in that the exemplars chosen for the memory set are all drawn from the same category. The slopes of the resulting response functions should parallel that of the initial experiment with the exception of category matches in the whole condition. Here, though exemplar memory set size may vary, category size is standardized at one. Thus, the slope should not be significantly different from zero. Should the latter occur, fairly conclusive evidence for a flexible cognitive system emerges.

Research investigating the notion of a parallel scan of independent codes has been completely confined to verbal material. While the scope of the research is somewhat limited, the results have favored the notion of parallel scanning.

Nielsen and Smith (1973) in a study designed to compare the parameters of "same" and "different" responses in a speeded recognition paradigm, simultaneously gleaned results indicative of dual storage codes. The memory set consisted of schematic or written descriptions of faces with five facial parts, each varying on three levels. The

number of relevant facial features to the recognition decision varied from three to five. Irrelevancy was defined by those features which did not vary in a test block. The probe was always a schematic face and was presented at one of two unfilled retention intervals; four or ten seconds. Results indicated a number of differences between "same" responses in the physical match and category match groups. "Same" RT was unaffected by the number of relevant facial features in the physical match condition, but increased linearly with the latter in the category match condition. "Same" RTs were faster in physical matches than category matches, and RT increased with increasing retention intervals in the physical match condition but decreased in the category match condition. The slope of the category match condition became shallower with increasing retention intervals, contrary to the physical match condition. Finally, errors were greater in category matches than physical matches. Results for "different" responses for the two groups paralleled one another but were consistently more pronounced with category matches. Generally then, "different" RTs, and errors, decreased as the difference between memory set and probe increased. With this difference constant however, "different" RTs increased with the number of relevant facial features. The variations in slope and RT for "same" and "different" responses between the two match conditions were interpreted to indicate a template (perceptual) comparison process in the physical match condition, and a verbal (conceptual) comparison process in the category match condition. Support for retrieval of both codes in the category match condition is tentatively indicated by the decreasing RTs with increasing retention intervals. Though this could indicate a

transformation of a conceptual to a perceptual code enabled by the increased delay, it could also indicate search of a persisting imaginal code (Nielsen and Smith, 1973).

Burrows and Okada (1973) auditorily presented memory sets of one to four words. Three levels of match type served as the independent variable; physical match, category match, and both match. A synonym of a memory set item was the criterion for a positive category match response, while either a synonym or a replica of a memory set item was the criterion for a both match response. A low error rate merited the elimination of error trials and positive and negative trials were collapsed as they were not significantly different. Analysis of the RT functions illustrated variation in slopes for the three match types. The slope for category matches was significantly greater than that for physical matches, indicating retrieval of different memory codes. The slope for both matches was significantly less than the sum of physical and category matches and, in fact, nearly identical to their average. Thus, a parallel scan of the two codes is suggested. Separate analysis of the two facets of the both match condition indicated no significant differences between its physical match component and the physical match condition, and its category match component and the category match condition. The intercepts varied with that for both matches being significantly higher than the combined intercept for physical and category matches. Burrows and Okada's interpretation of their results is in direct support of the extension of Atkinson, Herrmann and Wescourt's theory. They propose a serial encoding process followed by a parallel scan of two separate memory codes.

Burrows and Okada (1976) conducted a second, two-part study, the major purpose being to independently manipulate the two memory codes found in 1973. The experimental design for part one replicated that of their 1973 experiment. The stimulus ensemble was modified to include exemplars of categories and category labels. Memory set always consisted of category labels while probes were category labels for physical matches and exemplars of categories for category matches. The same trends as found in 1973 resulted. Independency of the two codes was teased out in the second part of the study. Experimental procedure was modified in the following fashion. Match type involved only both matches. Memory set always consisted of category exemplars and memory set size of three was deleted. The two and four item sets were divided into "fragmented" and "whole" trials. Physical match RT was found to increase linearly with set size in both "fragmented" and "whole" trials. Category match RT also increased linearly with memory set size in the "fragmented" condition but the slope was not significantly different from zero in the "whole" condition. This, along with a significant two way interaction between match type (physical or category match) and memory set size, was interpreted as indicative of independent retrieval codes. Error rate was low in all but "fragmented" category match trials. The heightened error rate and increased RT in these trials was proposed to result from increased processing necessary for response. The latter was supported by a significant match type by memory set size by trial type ("whole" or "fragmented") interaction.

Additional support can also be gleaned from a number of other studies (Besner, 1977; Cohen, 1969; Kirsner, 1970; Posner, 1969; Posner

and Taylor, 1969). The support is tentative however, as although the results are interpreted as indicative of retrieval as a parallel search of independent memory codes, the interpretations are based on accuracy of recognition or mean RT. The failure to extend analysis to slope comparisons leaves open the possibility of the results being indicative of encoding rather than retrieval processes.

The preceeding studies to greater or lesser degrees, provide evidence implicating retrieval of two independent memory codes for the same verbal stimulus information. Such evidence is nonexistent for motor stimulus information.

Research in the area of motor short-term memory (MSTM) runs into inherent difficulty with the stimulus set. Establishing movement items that firstly can be recognized as true items, and secondly, are not confuseable with any other item (Wilberg, Note 1) is a difficult task. In viewing the literature, much of the MSTM research has utilized different line lengths as the stimulus items. The widespread use of straight lines has resulted in a concurrent increase in knowledge regarding the coding of length information. Straight lines are least confounded by variables such as direction change (Hall and Leavitt, 1977) and intrinsic stimulus memory load. Psychophysically, a linear relation not only exists between physical length and visual length judgments (Eckman and Junge, 1961; Künnapas, 1958; Stevens and Galanter, 1957; Teghtsoonian, 1965; Teghtsoonian and Teghtsoonian, 1965) but also between physical length and haptic length judgments (Cheng, 1968; Teghtsoonian and Teghtsoonian, 1965). Relative threshholds, or the just-noticeable difference between two stimuli (jnd), have not been

directly determined for length judgments in any modality. Visually, however, the jnd must at least be below one-sixteenth of an inch (Blick, 1969). Lastly, an intrinsic problem with the use of length judgments revolves around perceptual biasing as a result of the range effect. Overestimation of short distances and underestimation of long distances is a central tendency effect that usually appears after a large number of trials (Wilberg and Hall, 1976). Conceivably, a small number of consecutive trials should minimize biasing due to the range effect. In overview, establishing a stimulus set of various lengths appears to be a valid method of coping with the uniqueness problem in movement information.

The purpose of the following series of experiments was to further investigate retrieval processes in a speeded recognition paradigm. The experiments were conducted across visual and haptic modalities and utilized various line lengths as the stimulus set. The length information supplemented previous research in visual STM and provides novel information regarding retrieval processes in MSTM. The purpose of experiment one, then, was to establish the possibility of a parallel scan of perceptual and conceptual codes for length information in both STM and MSTM. The purpose of experiment two was to illustrate independent manipulation of the two codes in STM. Such manipulation was necessary to insure the retrieval process was indeed utilizing two codes and not just two facets of one code.

EXPERIMENT I

Scanning of Perceptual and Conceptual Codes In STM And MSTM

Retrieval has been the subject of much verbal and visual investigation since Sternberg's 1969 exposition of the speeded recognition paradigm. Initial research was concerned mainly with verifying (Briggs and Blaha, 1969; Wingfield and Bolt, 1970), or negating (Atkinson, Holmgren, and Juola, 1969; Murdock, 1971; Okada and Burrows, 1974; Theios et al., 1973), Sternberg's hypothesis of a serial exhaustive scan. More recently, interest has been directed toward flexibility within the retrieval processes. Specifically, this research has been concerned with search of multiple independent storage codes for the same stimulus information.

In theoretical support of independent storage codes is a notion proposed by Atkinson, Herrmann and Wescourt (1974). Information processing is seen to revolve around perceptual (physical) and conceptual (meaning) codes. Input information is serially encoded from perceptual to conceptual code. Both codes are anchored, and thus stored in memory at conceptual nodes. STM speeded recognition tasks involve transfer of one of the two codes to STS where scanning takes place. To extend the theory in view of an optimal retrieval process, it becomes necessary that one, or both, codes be transferred to STS. Retrieval then becomes a function of a scan of the "optimal" code or codes for the particular task demand.

Empirical support of independent retrieval codes is somewhat limited. Results, however, have favored a perceptual-conceptual code notion (Burrows and Okada, 1973; 1976; Nielsen and Smith, 1973). Further

support can be tentatively gained from a number of other studies (Besner, 1977; Cohen, 1969; Kirsner, 1970; Posner, 1969; Posner and Taylor, 1969). The latter authors interpret their results as illustrative of retrieval processes. They utilize however, mean RT or accuracy of recognition as the dependent measure. In a speeded recognition paradigm, retrieval is illustrated by the slope of the response function (Sternberg, 1969). The failure to extend results to slope analysis leaves open the possibility of the data being indicative of encoding, rather than retrieval processes.

Research investigating retrieval codes in MSTM tasks is non-existent. A problem contributing to the lack of study is the difficulty in establishing unique items for the stimulus ensemble (Wilberg, Note 1). A viable method for coping with this problem appears to lie in the use of varying movement distances (line lengths). Psychophysically, a linear relation exists between both physical length and visual length judgments (Eckman and Junge, 1961; Künnapas, 1958; Stevens and Galanter, 1957; Teghtsoonian, 1965; Teghtsoonian and Teghtsoonian, 1965), and physical length and haptic length judgments (Cheng, 1968; Teghtsoonian and Teghtsoonian, 1965). Processing in the haptic modality however, is decidedly inferior to processing in the visual modality (Cashdan, 1968; Klein and Posner, 1971; Posner and Konick, 1966; Posner, 1967; Rock and Harris, 1967). Though jnd's have not been directly determined for movement length in any modality, it is safe to assume haptic jnd's would be greater than those for the visual modality. Visually, the jnd must at least be below one-sixteenth of an inch (Blick, 1969).

Psychophysical length studies aim to isolate the encoding of length from all other variables. The majority of psychophysical length

studies however, have utilized rods as their stimulus items. Rods necessarily have diameter. Diameter has been kept constant throughout the experiments. In a visual task, it is plausible that perceived length is influenced by stimulus diameter. In a haptic task, where the index finger and thumb are moved down opposite sides of the stimulus rod, confounding becomes even more probable. The question arises as to whether diameter does influence the coding of length information.

Research utilizing the speeded recognition paradigm has resulted in ambiguous findings regarding differences in RT between positive and negative responses. Atkinson, Holmgren, and Juola (1969), Atkinson, Herrmann and Wescourt (1974), Baddeley and Ecob (1970; 1973), Nickerson (1966), Okada and Burrows (1974), Sternberg (1969; 1975), Theios et al. (1973), Wickelgren and Norman (1966) and Wickelgren (1975) all found no difference in RT between positive and negative responses. Briggs and Blaha (1969), Burrows and Okada (1971), Forrin and Cunningham (1973), Howell and Stockdale (1975), Murdock (1971), and Nickerson (1965) all found negative responses to have slower RTs than positive. Differences may be due to the Ss experience with the task, variation in task difficulty, or variation in RT to response type (Nickerson, 1965). It is fairly well established that any difference is not due to a dominant-non-dominant side issue (Nickerson, 1965). RTs between the two hands and between the two feet are not significantly different, though hand RT is considerably faster than foot RT (Gagné and Fleishman, 1959).

The purpose of the following experiment was to further investigate the notion of optimal retrieval of one or two storage codes in STM tasks. Length information served as the stimulus set for visual and haptic

judgments. The results supplement previous pictorial research in visual STM and provide novel information regarding retrieval processes in MSTM. The stimulus set varied in diameter as well as length. The incorporation of varying diameters for the rod lengths provides additional insight into the coding of length information. The necessary inclusion of "same" and "different" response types in a speeded recognition paradigm, acts to shed further light on the issue of variation in response type RT.

Method

Subjects

Twelve students volunteered to serve as subjects for the experiment. Their ages ranged from sixteen to twenty-five. Four Ss were male and eight were female. One S was left-handed.

Apparatus and Task

Eight lengths of wooden dowling served as stimuli; 4, 4-1/2, 6-1/2, 7, 9, 9-1/2, 11-1/2 and 12 inches. Gaps of one-half inch marked exemplars of the same category, while gaps of two inches or more marked exemplars of four different categories. All lengths appeared in three diameters; 8, 12 and 16 mm. Each rod had a 1-1/2 inch nail driven in one end to the depth of 1/2 inch. Heavy gauge wire was driven in the other end, thereby extending the combined length of dowel, nail, and wire to at least 15 inches. The stimulus rods were presented to the subject in a 34 by 13 by 12 inch wooden box. The interior of the box was painted flat black and was divided into two parts. One partition (12 inches in length) held a 25 watt light bulb and was separated from the other by two opaque screens. The remaining side contained two 3-1/2 inch vertical bolts 14 inches apart. The bolts were sawn to a depth of 1 inch, forming a yoke. The stimulus rods were presented by resting them horizontally on the yokes. The nail end of the rod was always placed in the yoke on the S's left-hand side. Each rod began then, at the same place. On the experimenter (E) side of the box were two horizontally sliding doors. The left-hand door allowed access to the light bulb, while the right-hand door enabled the E to change the

stimulus rods. On the S side of the box was a 12-1/2 inch vertically sliding door. The door was connected to a removeable wire spring on the inside of the box. It was held down by a latch on the top of the box. Pressing the latch enabled the extended spring to recoil, and thus the door opened. The S sat in a comfortable chair in front of the apparatus. His feet rested on two independent foot pedals. The right pedal was designated the "same" pedal, and the left, the "different" pedal. Pressing the right foot pedal simultaneously drove a sensor light enabling E to delineate response type. The apparatus was connected to a PDP 10/11 computer.

Visual Task

The S sat directly in front of the vertically sliding door. While the door was closed, E placed a stimulus rod in the yoke of the vertical bolts inside the box. E then pressed the latch thereby releasing the door. The elapsed time for complete door opening did not exceed 0.317 secs. After approximately one second, E closed the door. This constituted the presentation of a single stimulus item within a trial. The number of stimulus rods presented in a trial equalled the memory set size for that block of trials, plus one. The last stimulus rod presented was the test item, or probe, for that trial.

Full opening of the door activated a microswitch mounted inside the box. The computer registered each time the microswitch was activated. E programmed the computer to commence timing when the microswitch had been activated the appropriate number of times for each respective memory set size. RT interval was ceased when S pressed either of the two foot pedals. The computer recorded RT while E recorded accuracy of response.

Haptic Task

The S sat on the left of the apparatus if he was right-handed, and to the right if he was left-handed. The vertically sliding door was propped open. S wore opaqued ski goggles. S placed the index finger on the dominant hand at the base of the left-hand yoke. The finger was then moved up the yoke to contact the nail, and to the right to contact the end of the rod. The index finger was placed on top, and the thumb underneath the rod. S was instructed to wait until he received the command to "start." He then had a maximum of 2 seconds to slide his finger and thumb to the end of the rod. A Hunter interval timer measured the passage of time. The time limit was required to prevent S from scanning memory information before reaching the end of the rod. If the 2 second time period was exceeded a tone sounded indicating a void trial. On probe presentation a microswitch was placed approximately one finger width from the end of the rod. S automatically pressed the switch with his index finger when he reached the end of the rod. Closure of this switch signalled the computer to commence timing. The RT interval was ceased when S pressed either foot pedal. The computer recorded RT while E recorded accuracy of response.

Procedure

Each trial began with the sequential presentation of a memory set of 1, 2 or 3 rods. Visual presentation rate was approximately 1.5 seconds per item, and haptic, approximately 2 seconds per item. Memory set presentation was followed by a probe to which S responded either "same" or "different." The trials were blocked into units consisting of 4 practise trials and a minimum of 16 test trials. The S received

18 blocks of trials over a 24 day period. Modality, match type, and memory set size were fixed within each block. Within a block, testing continued until the correct response was given to each trial. Error trials were retested at the end of a block. Correct response to 5 consecutive "dummy" trials was required before an error trial could be interpolated. Of the 16 test trials in a block, 8 required "same" responses and 8 "different" responses. Response type was randomized with the restriction that no more than 3 trials of any response type could occur consecutively. Serial position of the positive test items was randomized.

The Ss were randomized into two equal groups. One group received all visual trials first, while the other received all haptic trials first. Within each modality there were 3 match types. Physical matches required a same response if the probe was physically the same length as any memory set item. Category matches required a same response if the probe was an exemplar of any of the categories represented by the memory set items. Both matches required a same response if the probe was either a physical match or category match of any of the memory set items. Within the both match condition, 4 of the 8 positive trials were physical matches and 4 were category matches. Match type was randomized without replacement within each modality. For each S, randomization was restricted so that no match type could occur in the same position as it had in the first modality tested.

Each S received all 6 permutations of the 3 memory set sizes; 3 for each modality. Within a modality, no memory set size permutation could occur with the same match type over the 6 Ss in a group. Within

memory set size of one, the following 2 diameter permutations occurred: a) memory set and probe same diameter, and b) memory set and probe different diameter. Diameter type was randomized with the restriction that 4 of each diameter type occur within positive and negative responses in each block. Within memory set sizes two and three, the following 4 diameter types could occur: a) all memory set items same diameter--probe same diameter; b) memory set items different diameter--probe different diameter; c) memory set items same diameter--probe different diameter; and d) memory set items different diameter and probe same diameter as one of the memory set items. In this case, diameter type was randomized with the restriction that each diameter type occur equally within positive and negative trials within each block. Both match trials were specially restricted in that all 4 diameter types had to occur once for physical matches and once for category matches in the positive trials.

All Ss were familiarized with the task before testing began. Each S received 1 day of visual practise and 2 days of haptic practise before testing in the respective modality began. The practise sessions were divided into blocks of trials. A block was defined by a match type paired with a particular memory set size. Five consecutive correct responses were required in each block. The S received all match types, memory set sizes, diameter types, and response types in a practise session. Before a practise session began, each S was given the exemplars of the 4 categories. They were told the exemplars represented the longest and shortest item in each category. The Ss were able to refer to the exemplars any time during practise. Before each practise and

testing session, it was stressed that the S must not sacrifice accuracy for speed. These instructions were given to ensure that all Ss were operating under the same portion of the speed-accuracy curve.

During visual test trials, the S could refer to the exemplars of the categories before the test block began. In haptic testing, the S's were required to feel the exemplars every 5 trials.

Design and Data Analysis

Initially, an analysis of variance was conducted for each memory set size. Within each memory set size, 5 factors were of interest: a) order of presentation with 2 levels; b) match type with 3 levels; c) response type with 2 levels; d) diameter type with 2 or 4 levels; and e) replications with 2 or 4 levels. The factors for memory set size one are incorporated into a 2 x 3 x 2 x 2 x 4 factorial design with Ss nested in order of presentation. For memory set sizes two and three, the design is a 2 x 3 x 2 x 4 x 2 factorial with Ss nested in order of presentation.

Secondary analysis included least squares linear regression on mean RT and memory set size for each match type. Scheffé's test was then conducted on the slopes of the lines.

Percentage error rate was computed for each block of trials.

Results

Order of presentation was significant for memory set sizes one and two, $F(1, 132) = 56.33$, $p < .01$ for memory set size one; $F(1, 264) = 13.59$, $p < .01$ for memory set size two. Order did not reach significance for memory set size three, $F(1, 264) = 2.48$, $p > .01$. In viewing Figure 1, it is evident that the visual trials are responsible for the significant order effect. The match type x order interaction was also significant in memory set size two, $F(2, 264) = 4.88$, $p < .01$. All other components of the analyses of variance failed to reach significance. The data were collapsed over all factors but modality, match type and order of presentation, for further analyses.

Figure I is a graph of mean RT as a function of memory set size. The set size effects appear to depart from linearity. Lines of best fit for the set size effects are found in Table I. Inspection of Table I shows that for each modality and order of presentation, the slope of the both match condition is less steep than the sum of the slopes of the other two match types. This difference is significant only in the case of Table IA, $F(1, 45) = 4.80$, $< .05$. Table IB approached significance, $F(1, 45) = 3.81$, $p > .05$. Both haptic groups were not significant, $F(1, 45) = 1.07$, $p > .05$ for Table IC; $F(1, 45) = 1.13$, $p > .05$ for Table ID.

The slopes of the lines of best fit for physical and category matches within the visual both match condition are found in Table II. There was no significant difference between these slopes and those obtained under the pure physical match and category match conditions, $F(1, 2) = 1.45$, $p > .05$ for Table IIA; $F(1, 2) = .59$, $p > .05$ for Table IIB.

Figure 1

Mean RT as a Function of Memory Set Size for each Match Type, Modality, and Order of Presentation

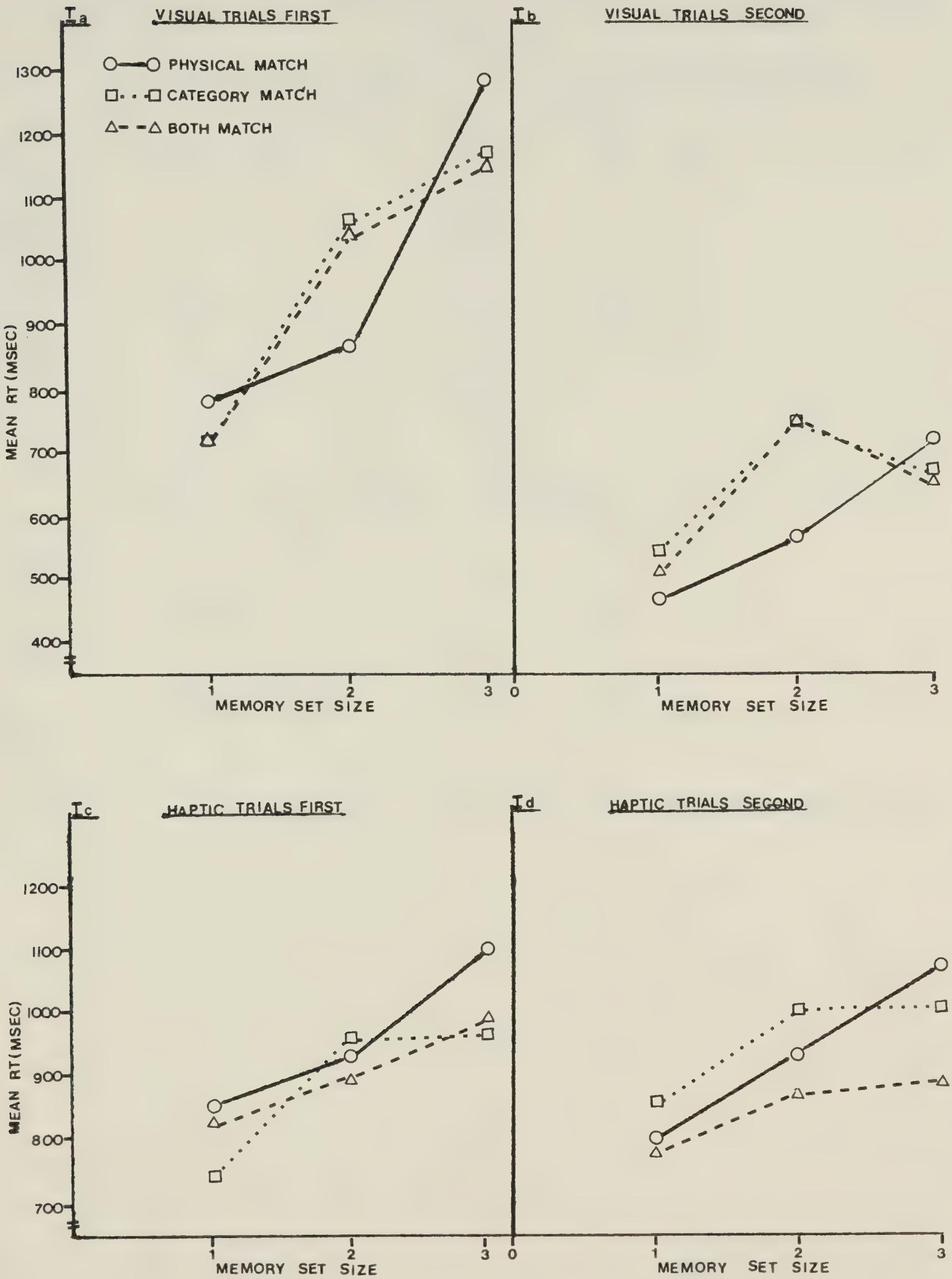

Table I

Slopes and Intercepts of the Lines of Best Fit for the Three Match Types in each Modality and Order of Presentation

	VISUAL	
	IA Visual Trials First	IB Visual Trials Second
Physical Match	239M + 493	83M + 427
Category Match	213M + 549	61M + 523
Σ	452	144
Both Match	207M + 545	75M + 481
	HAPTIC	
	IC Haptic Trials First	ID Haptic Trials Second
Physical Match	126M + 702	136M + 654
Category Match	106M + 672	51M + 848
Σ	232	187
Both Match	77M + 739	53M + 743

Table II

Slopes of the Lines of Best Fit for Physical and Category Matches within Visual Presentations of the Both Match, Match Type

	IIA Visual Trials First	IIB Visual Trials Second
Physical Match	208	112
Category Match	159	98

Percentage error rate for both modalities and orders of presentation are found in Table III. Errors tend to systematically increase with memory set size and be greatest for category matches. Within a modality, errors are greater for the group which received that particular modality first. This difference was significant only in the visual modality, $F\ (1, 16) = 4.76$, $p < .05$ for the visual modality; $F\ (1, 16) = 3.88$, $p > .05$ for the haptic modality.

Table III

Percentage Error Rate in Both Modalities and Orders of Presentation as a Function of Memory Set Size for the Three Match Types

VISUAL

	Visual Trials First			Visual Trials Second		
	Memory Set Size			Memory Set Size		
	1	2	3	1	2	3
Physical Match	1.96	2.70	5.64	0.94	0.00	4.31
Category Match	0.93	4.31	4.55	1.00	0.93	1.92
Both Match	0.93	3.13	4.10	0.00	3.13	1.80

HAPTIC

	Haptic Trials First			Haptic Trials Second		
	Memory Set Size			Memory Set Size		
	1	2	3	1	2	3
Physical Match	8.89	10.13	15.76	8.77	7.78	11.33
Category Match	12.32	15.84	18.07	10.63	10.42	14.38
Both Match	8.33	11.56	14.38	5.55	11.52	9.93

Discussion

Visual and haptic length judgments can be made uninfluenced by diameter. Accuracy of response and speed of RT to a visual judgment however, are influenced in a significantly positive fashion when haptic trials are given first.

Concurring with Atkinson, Holmgren, and Juola, 1969; Atkinson, Herrmann,and Wescourt, 1974; Baddeley and Ecob, 1970; 1973; Nickerson, 1966; Okada and Burrows, 1974; Sternberg, 1969; 1975; Theios et al. 1973; Wickelgren and Norman, 1966; and Wickelgren, 1975, positive and negative responses were not significantly different. This supports the notion of an exhaustive scanning process (Atkinson, Herrmann, and Wescourt, 1974; Nickerson, 1966; Sternberg, 1969;1975). Contrary to the latter theories however, in viewing Figure 1 it is obvious there are definite deviations from a linear increase in RT with increasing memory set size. The deviations are most obvious in: a) category matches, b) both matches, and c) the second modality tested. These deviations may be explained by the development of an optimal response strategy on the part of the Ss. The Ss were informed that physical matches and category matches were contained in the both match condition. They were also aware that there were only four length categories. In memory set size three, an optimal search strategy for both match and category match conditions would be to scan the one remaining category rather than the three categories of the memory set. Such a strategy would not be efficient for physical matches, as the alternatives not presented always out-numbered those presented. The fact that the difference is more pronounced in the second order of presentation

would indicate the strategy was developed during, and not before, the experiment began. Ss comments taken after each modality tested support such an interpretation.

Atkinson, Hërrmann, and Wescourt (1974) propose a serial encoding process from perceptual to conceptual code. The slopes and intercepts of the lines of best fit for the data are found in Table I. The physical match and category match intercepts generally support previous results indicating such a notion (Burrows and Okada, 1976). Table IC however, is an exception. A probable explanation for the latter deviation revolves around E stressing an accurate rather than speedy response. Categorical length information is necessarily redundant. Consequently, the error bandwidth for category matches is larger than that for physical matches. Viewing the error data presented in Table III, it appears that not only are haptic judgments more difficult to make than visual ones, but within the haptic trials, physical matches are more difficult than category matches. It is probable that the Ss receiving the haptic trials first took longer to encode physical information in compliance with the smaller error bandwidth. This would not occur in visual trials, or when the haptic trials composed the second modality tested, as a result of the Ss gaining confidence in their ability to recognize the various exemplars. Once again, the latter interpretations are supported by the Ss comments taken after each modality tested.

The slopes of the lines of best fit for the various match types are found in Table I. In all cases the slopes for physical matches are greater than those for category matches. It appears that

a scan of physical information is slower than a scan of category information. It is very possible that this is an artifact of the limited category size. As such however, the results are in opposition to Burrows and Okada's (1973; 1976) data for verbal information.

In accordance with previous results (Burrows and Okada, 1976), the sum of the slopes of the physical and category match types is greater than that for the both match, match type. It appears that in the both match condition, the S must have been able to execute a physical and category scan in overlapping fashion. Had the scans been done serially, the slope for the both match condition would have equalled the sum of the slopes of the physical and category match types. A significance test between these slopes however, casts serious doubts on a parallel scan of haptic length information. In contrast to the visual results, the haptic results for both orders failed to reach significance. This statistic could be intimating a different memory system or memory processes for haptic length information. On the other hand, it too, could be an artifact of the limited category size. Processing in the haptic modality is inferior to visual processing (Cashdan, 1968; Klein and Posner, 1971; 1967; Posner and Konick, 1966; Rock and Harris, 1967). It is possible the limited category size had greater impact on haptic statistics than visual statistics. In summary then, parallel scanning of physical and category haptic length information cannot be accepted on the grounds of the slope differences failing to approach significance. On the other hand, the notion cannot be disregarded on the grounds of differences between the sums of slopes.

Parallel scanning of physical and category information was supported in the visual modality. The significance test between the sum of the physical and category match type slopes, and the both match slope, yielded a trend towards, and a significant result for the two orders of presentation. As found by Burrows and Okada (1976), parallel scanning was further supported by a breakdown of the both match condition. The slopes of the physical and category match types within the both match condition were not significantly different from those obtained in the pure physical and category match conditions. It appears that upon presentation of the probe, the Ss simultaneously scanned a physical and category code. If the probe was a physical match, the S made a positive response when all physical comparisons were completed. If the probe was a category match, the S responded positively when all category comparisons had terminated.

The following STM experiment verified the proposal that Ss do eliminate presented memory sets in favour of a smaller subset of remaining information. In this experiment, elimination acted to distort the lines of best fit for data obtained in the category and both match conditions. Appendix A is a table of the lines of best fit for these two match types calculated over only memory set sizes one and two.

EXPERIMENT II

Independent Perceptual and Conceptual Codes in STM

The results of experiment I were interpreted to support the notion of dual memory codes for visual length information. The results however, do not rule out a second interpretation. Rather than a parallel scan of independent memory codes, two operations may have been occurring on a single memory code. To illustrate, the Ss may have simply been remembering the memory set items as presented. Physical matches would then be a result of a direct comparison process. Category matches, on the other hand, would require converting the probe to its appropriate category label. Before the memory set items could be compared, they too, would have to be converted to their respective category names. It is readily apparent that an optimal search process would be a parallel scan of independent memory codes. The purpose of experiment II was to resolve the two interpretations.

Assuming an optimal search process, the two memory codes should be able to be manipulated independently. Drawing all memory set items from the same category should have varying effects on RT to physical matches and category matches. Physical matches would require comparison of the probe to all memory set items. Category matches, on the other hand, should result from comparison of the probe to the one appropriate category instance, regardless of memory set size. Code independency would then be illustrated by the slope of the RT functions. While the slope for physical matches would be illustrative of a scan of increasing items with increasing memory set size, the slope for category matches would exhibit no such increase. Statistically, the

slope of the RT function for category matches would be equal to zero.

Trials where the memory set items were drawn from different categories (fragmented trials) were used in experiment II, along with those trials utilizing memory set items drawn from the same category (whole trials). Fragmented trials gave a baseline against which the effect of whole trials could be evaluated. They also provided additional information regarding cognitive strategies believed to be occurring in experiment I. The number of categories used in experiment II were increased from the number used in experiment I. Thus, the decrease in RT obtained with category and both matches in memory set size three would not be as pronounced. This is assuming Ss do indeed, eliminate the categories of the presented memory set to a memory set of the fewer remaining category codes.

Method

Subjects

Six students from the first experiment volunteered to serve in the second experiment.

Apparatus and Task

Twenty-five lengths of 16 mm wooden dowling served as stimuli (1, 1-1/2, 2, 2-1/2, 3, 4-1/2, 5, 5-1/2, 6, 6-1/2, 8, 8-1/2, 9, 9-1/2, 10, 11-1/2, 12, 12-1/2, 13, 13-1/2, 15, 15-1/2, 16, 16-1/2, and 17 inches). Gaps of 1/2 inch marked the 5 exemplars of each of 5 categories. The categories were differentiated by a minimum of 1-1/2 inches. A 1/2 inch nail was driven in one end of each rod to a depth of 1/2 inch. Heavy gauge wire was driven in the other end extending the lengths to at least 18 inches. The test box was the same as that used in experiment I. As the rods were longer in experiment II, the vertical yokes were separated to a distance of 17-1/2 inches.

The task was identical to the visual task in experiment I. In experiment II however, S sat slightly to the left of centre of the vertically sliding door. This was to insure S could see the entire length of the longest rod without shifting head position.

Procedure

Each trial began with the sequential presentation of a memory set of 1, 2, or 3 rods. Presentation rate was approximately 1.5 secs./ item. Memory set presentation was followed by the test item or probe. S responded "same" if the probe was physically or categorically identical to any memory set item. Each S received 3 blocks of test trials. One

block of 16 trials served as memory set size one, and 2 blocks of 28 trials served for each of memory set sizes two and three. The variation in trials per block equalized the number of data points collapsed into mean RT for the various RT functions. The first 4 trials in every block were practise trials. Within memory set size one, 4 trials were physical matches, 4 were category matches, and 4 were neither physical nor category matches (no matches). Within memory set size two and three, there were 8 trials for each of the three match types. The latter trials were subdivided so that for each match type, half of the trials were "whole" and half were "fragmented." The order of whole and fragmented trials was random, as was serial position of positive test items. Positive and negative responses were randomized with the restriction that no more than four of any one response type could occur sequentially. Lastly, memory set size presentation was randomized without replacement between Ss.

All Ss were familiarized with the exemplars and categories before testing began. Each S received 3 blocks of practise trials. Within a block, memory set size was fixed and all possible match types, trial types, and response types occurred. A criterion of 8 sequentially correct responses was required before testing in the next block could begin.

Design and Data Analysis

Initially, an analysis of variance was conducted on each memory set size. Within memory set size one, 2 factors were of interest; match type and replications. The design for memory set size one became then, a two way factorial with replications as a repeated measure.

Within memory set size two and three, 3 factors were of interest; match type, trial type, and replications. The design for memory set size two and three became a three way factorial with replications once again, a repeated measure.

Least squares linear regression was computed on mean RT of the three memory set sizes for each combination of match type and trial type. The slope of the line of best fit for whole trials was then tested against zero using Pearson Product Moment correlation.

Percentage error rate was calculated for each memory set size, trial type, and match type as well as for each combination of match type and trial type within a memory set size.

Results

Analysis of variance resulted in a significant trial type effect, $F(1, 30) = 5.91$, $p < .05$ for memory set size two; $F(1, 30) = 14.68$, $p < .05$ for memory set size three. In viewing Figure 2, it can be seen that the effect occurs in category matches and no matches. Supporting this is a significant match type x trial type interaction in memory set size two, $F(6, 90) = 2.57$, $p < .05$. Further analyses were collapsed over replications.

Mean RT as a function of memory set size for all match type and trial type combinations, is found in Figure 2. Memory set size one was included in both trial types for completeness. The set size effects for fragmented trials depart from linearity, while those for whole trials are markedly linear. The slopes and intercepts of the lines of best fit for each of the RT functions are found in Table IV. Correlation between memory set size and RT resulted in insignificant T values for whole category match trials and whole no match trials, $T(70) = .026$, $p > .05$ for category matches; $T(70) = .114$, $p > .05$ for no matches. Thus, the slopes of the latter two RT functions were not different from zero.

Percent error rates for each match type and trial type within a memory set size, along with percent total error rates, are found in Table V. The total error rates indicate that of the two trial types, fragmented trials were more prone to error. Within trial types, category matches had the most errors followed by no matches and then physical matches. Lastly, memory set size two had more errors than memory set size three and one.

Figure 2

Mean RT as a Function of Memory Set Size for each Match Type and Trial Type Combination

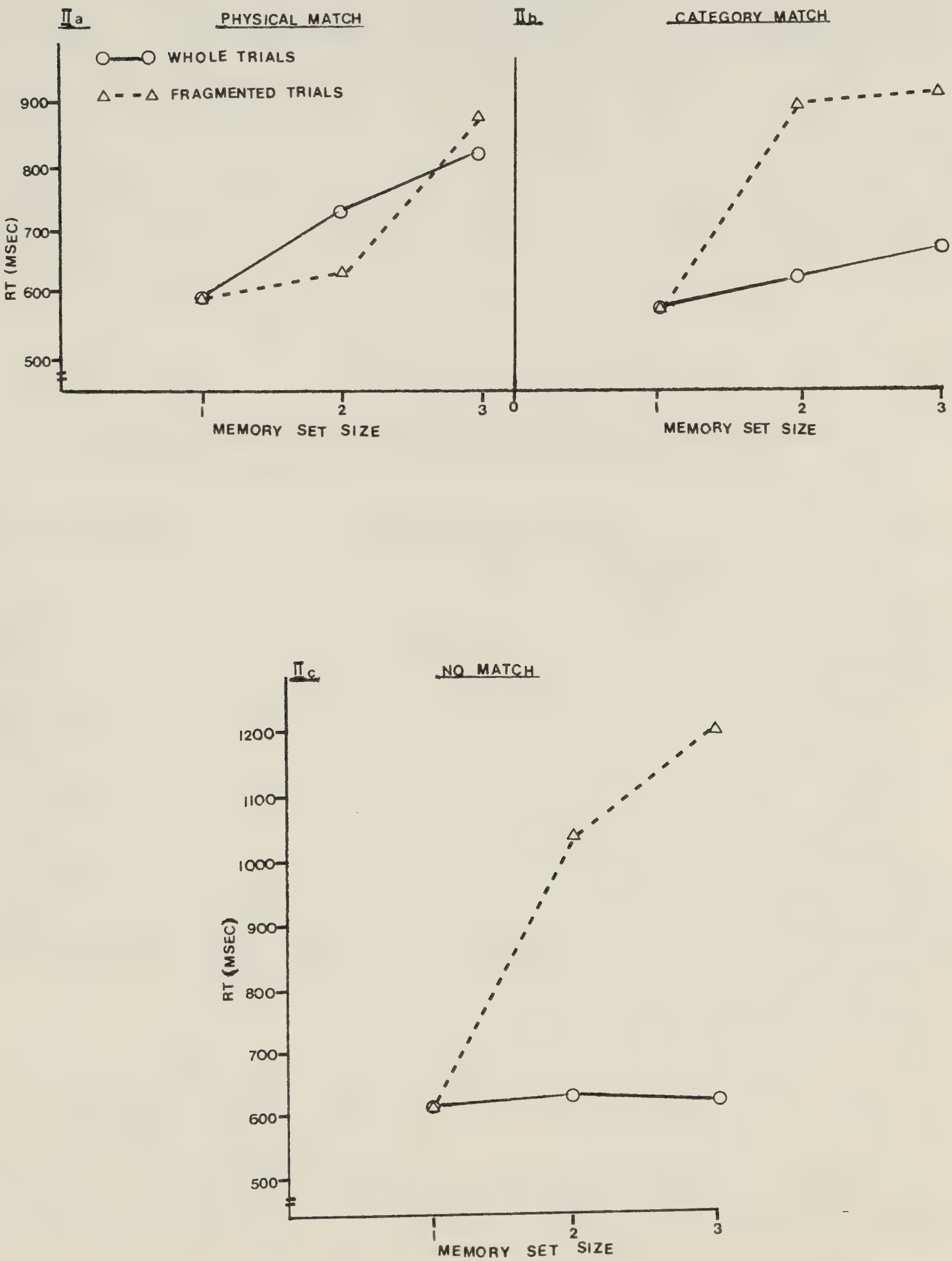

TABLE IV

Slopes and Intercepts of the Lines of Best Fit for each Match Type and Trial Type Combination

Trial Type	Match Type		
	Physical Match	Category Match	No Match
Whole	105M + 499	48M + 539	4M + 612
Fragmented	145M + 413	151M + 477	294M + 364

TABLE V

Percent Error Rate for Each Match Type and Trial Type within a Memory Set Size, and Total Error Rates

Match Type	Whole Trials				Fragmented Trials			
	Memory Set Size				Memory Set Size			
	1	2	3	Total	1	2	3	Total
Physical Match	0.0	0.0	0.0	0.0	0.0	8.3	0.0	1.4
Category Match	4.2	8.3	0.0	4.2	4.2	16.7	8.3	9.7
No Match	0.0	0.0	4.2	1.4	0.0	8.3	4.2	4.2
Total	1.4	2.8	1.4	1.9	1.4	11.1	4.2	5.6

Discussion

The RT functions for fragmented trials deviate from linearity (Figure 2). In contrast to experiment I however, there is never a decrease in RT with increasing memory set size. On the other hand, there is little increase in RT from memory set size two to three in Figure IIb. It appears that Ss do indeed, incorporate an optimal search strategy when the stimulus ensemble is small. In experiment I, when the memory set contained three items, the conceptual code could be optimally rearranged to contain the one category not presented. In experiment II where the stimulus ensemble held five categories, the conceptual code in memory set size three could be rearranged to contain the two remaining category instances. Code adjustment would be reflected in mean RT. RT appropriately decreases from memory set size two to three in the second order of presentation of visual trials in experiment I (Figure Ib). Approximately equal RTs to the two memory set sizes are found in experiment II (Figure IIb).

Concurring with Burrows and Okada (1976), the results overall, are indicative of a parallel scan of independent memory codes. In viewing the slopes of Table IV, it appears that physical matches warranted a scan of all memory set items presented, regardless of trial type. The slopes of the RT functions for category matches and no matches, on the other hand, were pronouncely influenced by the type of trial. Category and no match fragmented trials have slopes of over 150 msec./item. In both cases however, the slope of the RT function for whole trials was less than 50 msec./item. The latter slopes were not different from zero. This suggests the Ss were responding on the

basis of an optimal conceptual code; the one appropriate category instance. The dichotomous effect of trial type on match type is further supported by the significant match type x trial type interaction in memory set size two. The opposing effect of trial type on RT to the various match types indicates the perceptual and conceptual codes are being separately manipulated, and thus, are independent.

In contrast to experiment I, the slope for fragmented physical match trials is less than the slope for fragmented category match trials. This is further supported by no match trials. As found by Burrows and Okada (1976), scanning in the perceptual code appears to be faster than scanning in the conceptual code.

The intercepts of the lines of best fit are also found in Table IV. Looking across fragmented trials, the intercept for the physical match condition is less than that for category comparisons. This difference, concurring with Burrows and Okada (1976), supports the notion of serial encoding from perceptual to conceptual code. It is important to note that the intercepts resulting from whole trials cannot be compared. As the slope for whole category match trials is not significantly different from zero, the intercept becomes confounded with scan time. Such is not the case however, for whole physical match trials. Comparison between the intercept of whole physical match trials and fragmented category match trials should ideally yield then, a lower intercept for the physical match trials. Opposing results are seen in Table IV. The apparent contradiction is tempered by the error data outlined in Table V. The error rate was much greater in fragmented than whole trials. This difference intimates variation in trial type

difficulty. As such, comparison of processes proposed to be occurring within the trial types is dubious, unless initial differences can be accounted for.

In viewing Table V, and once again concurring with Burrows and Okada (1976), it appears that there is a trend toward increasing error with trials requiring greater processing. Fragmented trials, which require processing of memory set items from a number of categories, have more errors than trials where memory set processing is confined to a single category. Conceptual code responses are more errorful than responses based on the initially acquired perceptual code. In contrast, memory set size two has more errors than memory set size three. As this did not occur in experiment I, it is probable the deviation is a result of the individual trials making up the test block.

General Discussion

STM retrieval processes have been the concern of much recent research. Sternberg's (1969) additive theory of RT spurred investigations into the processes proposed to be occurring in the comparison stage, as well as into the basic premise that retrieval is the result of a scanning process. Little concern however, has been directed toward the general structure of the information being scanned. In the same vein, there is a paucity of information regarding characteristic traits of the memory codes retrieved in motor short-term memory (MSTM) tasks. The purpose of this series of studies was to shed light on the general structure of, and processes operating on, STM and MSTM retrieval codes.

Man can be thought of as an optimizer. Optimal behaviour in a fluctuating environment requires flexibility. A possible source of flexibility lies in the storage of multiple memory codes for the same stimulus information. Retrieval, as an offshoot, becomes a function of acquisition and search of the optimal code or codes for the particular task demand.

The notion of storage of both perceptual and conceptual codes in memory provides a theoretical base for an optimal retrieval process (Atkinson, Hermann, and Wescourt, 1974). A speeded recognition paradigm with variations in response criterion provides the practical framework for investigating such a theory. The resulting RT, with appropriate statistical manipulations, exists as empirical evidence which can be

interpreted as either lending support to, or away from, the notion of a parallel scan of perceptual and conceptual memory codes.

Investigation into retrieval of length information in MSTM yielded dichotomous results. Basic calculations were interpreted as supporting a dual coding notion. More stringent statistics however, could only be construed to reject such a notion. Further research is necessary before the argument can be weighted in favour of one of the interpretations.

Visual length information, on the other hand, yielded results interpreted as solidly supporting the notion of dual retrieval codes. As such, retrieval of visual length information is in accordance with previous visual and verbal STM research (Burrows and Okada, 1973; 1976; Nielsen and Smith, 1973).

Independent manipulation of the perceptual and conceptual codes in a visual STM task, acted to rule out an alternative notion that two operations were being carried out on a single memory code. The latter rejection further supports a dual coding notion. It also warrants the following proposal of a powerful retrieval mechanism. Retrieval revolves around a serial scan of a single "optimal" memory code, or a parallel scan of two independent memory codes for the same stimulus information. One memory code, the perceptual code, contains information existing at a purely physical level. The second, or conceptual memory code, contains information akin to primitive meaning features not dependent on physical form. Information integrity is maintained in the perceptual code. The conceptual code on the other hand can be reduced by reorganization. Reorganization can take the form of compacting the presented information,

or eliminating it entirely in favour of a smaller subset of remaining material. Response, in summary, becomes a function of retrieval of the "optimal" code or codes for the particular task demand.

Lastly, studies investigating the coding of length information have accumulated in the literature (Blick, 1969; Cheng, 1968; Eckman and Junge, 1961; Hall and Leavitt, 1977; Künnapas, 1958; Stevens and Galanter, 1957; Teghtsoonian, 1965; Teghtsoonian and Teghtsoonian, 1965; Wilberg and Hall, 1976). Supplementing this research is the knowledge that STM and MSTM length information can be coded uninfluenced by diameter.

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Note 1: Wilberg, R.B., Personal communication, Jan. 19, 1978.

APPENDIX A

APPENDIX A

Slopes and Intercepts of the Lines of Best Fit
Calculated over Memory Set Sizes One and Two
in the Category Match and Both Match
Conditions of Experiment I

	Visual Trials First	Visual Trials Second
VISUAL		
Category Match	323M + 402	191M + 350
Both Match	305M + 415	225M + 280
HAPTIC	Haptic Trials First	Haptic Trials Second
Category Match	219M + 555	115M + 762
Both Match	63M + 758	93M + 690